Bulk-Level Models for Solar Grid Interconnection and Planning

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WECC Renewable Energy Modeling TF

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Planning Studies and Grid Models

- Generator interconnection studies
  - Required under LGIP/SGIP
  - Proposed project portfolios (near-term)
- T&D planning studies
  - Mandated by NERC
  - Local/regional scope
- Future scenarios
  - For example, high will grid reliability be impacted by high penetration scenarios of renewables?
    - Lower inertia, dispatch/variability, generation patterns

Studies at Transmission Level

- Power flow models
  - Overloads, steady-state voltage stability & control
- Dynamic stability models
  - Rotor angle stability, dynamic voltage recovery
- Short circuit models
  - Breaker duty, protection design/coordination
- Detailed high-order models
  - Control interaction, harmonic analysis…

Conventional models OK for conventional CSP, but not PV

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Studies at Transmission Level

Type of Model	Gaps
Power Flow*	• Better modeling of reactive capability/control • Collector system effects, equivalent representation
Dynamic*	• Validated, generic, non-proprietary, accessible standard-library models (NERC requirement) • Available in industry-standard simulation platforms • Emerging real/reactive power management features • Include variability???
Short Circuit	• Collector system effects

- General: Integration with distributed planning; application guides

* Within charter of WECC REMTF (PV)

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WECC REMTF Charter

- Develop and validate generic, non-proprietary, positive-sequence power flow and dynamic simulation models for distribution-connected and transmission-connected solar and wind generation in large-scale simulations
- Issue guidelines, model documentation
- Coordinate with stakeholders groups

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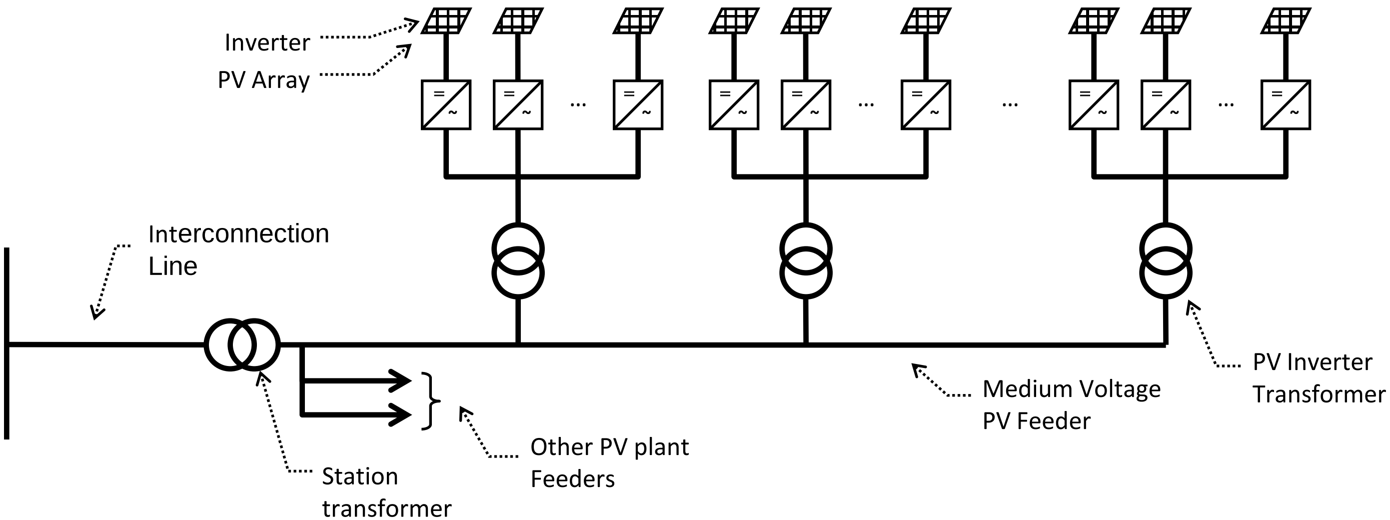
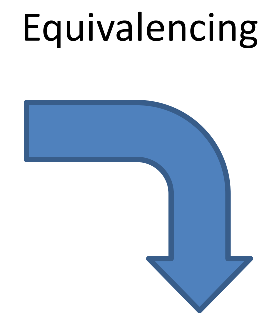
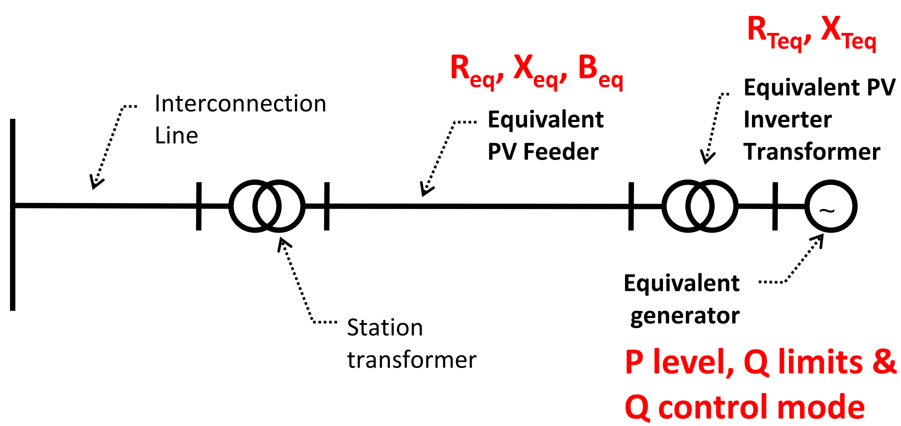
Power Flow Representation





Model interconnection line and station transformer explicitly, if they exist



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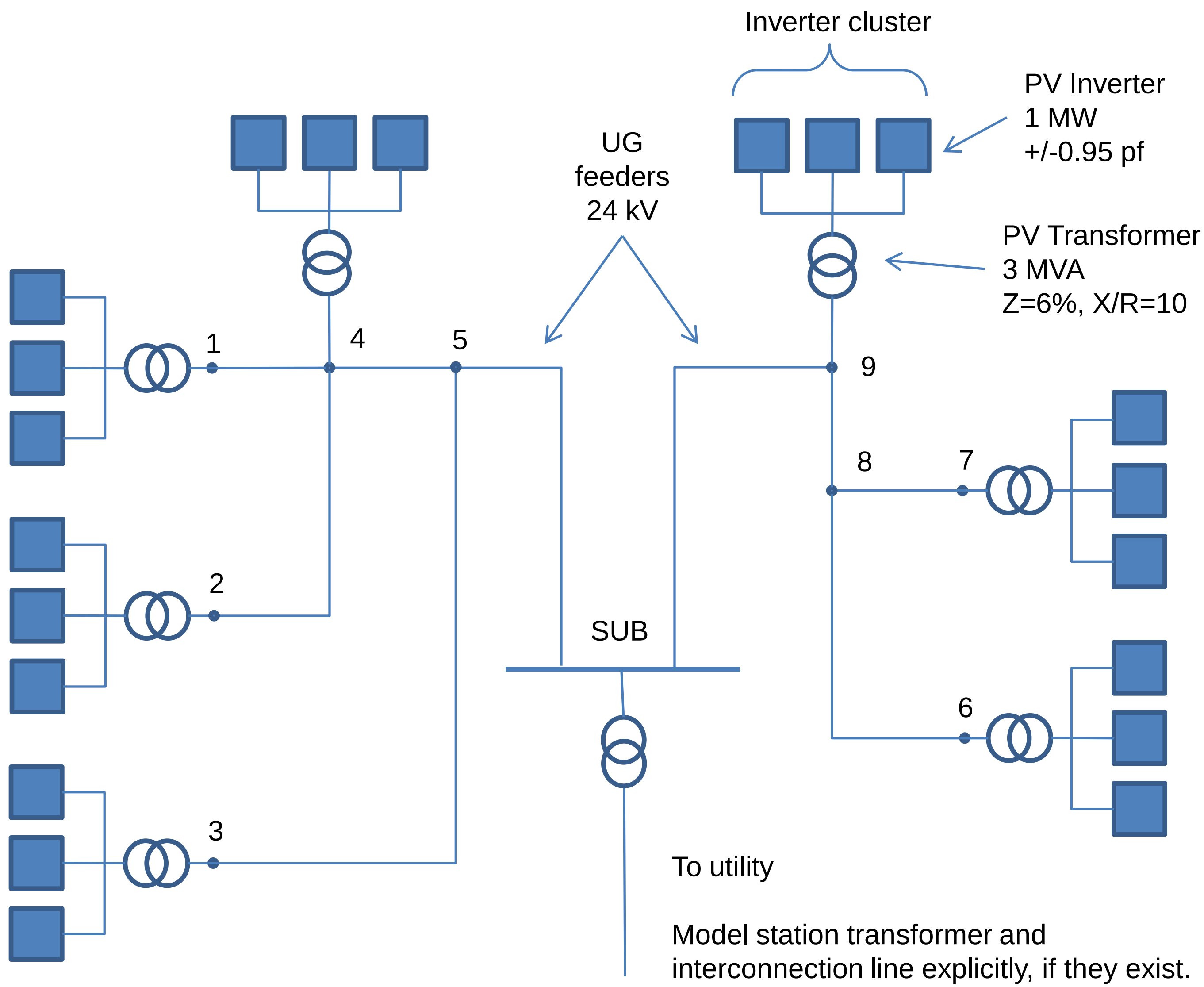
An Example



Model station transformer and interconnection line explicitly, if they exist.

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An Example

Collector System Equivalent on 100 MVA base, 24 kV

From	To	R	X	B	n	R n^2	X n^2
1	4	0.03682	0.00701	0.000000691	3	0.33136	0.06307
2	4	0.02455	0.00467	0.000001036	3	0.22091	0.04205
4	5	0.02455	0.00467	0.000001036	9	1.98816	0.37843
3	5	0.02557	0.02116	0.000000235	3	0.23016	0.19042
5	**SUB**	**0.02557**	**0.02116**	**0.000000235**	**12**	**3.68251**	**3.04673**
6	8	0.03747	0.00868	0.000000561	3	0.33726	0.07809
7	8	0.02455	0.00467	0.000001036	3	0.22091	0.04205
8	9	0.02109	0.02501	0.000000199	6	0.75925	0.90025
9	**SUB**	**0.02109**	**0.02501**	**0.000000199**	**9**	**1.70831**	**2.02555**

RESULTS

Partial R sum	9.4788
Partial X sum	6.7666
N	21

Collector System Equivalent

(Same units as R, X & B data)

Req	0.021494	pu
Xeq	0.015344	pu
Beq	0.000005	pu

PV Transformer Equivalent

$$Z_{Teq} = \frac{Z_T}{M} = \frac{0.00597 + j0.05970}{7} = 0.00085 + j0.00853 \quad \text{pu on 3 MVA base}$$

$$= 0.02843 + j0.28430 \quad \text{pu on 100 MVA base}$$

PV Generator Equivalent

$$Pgen = 1\,MW * 21 = 21\,MW$$

$$Q\min = -Q\max = Pgen \times \tan\left(\cos^{-1}(PF)\right) = 6.9\,MVAR$$

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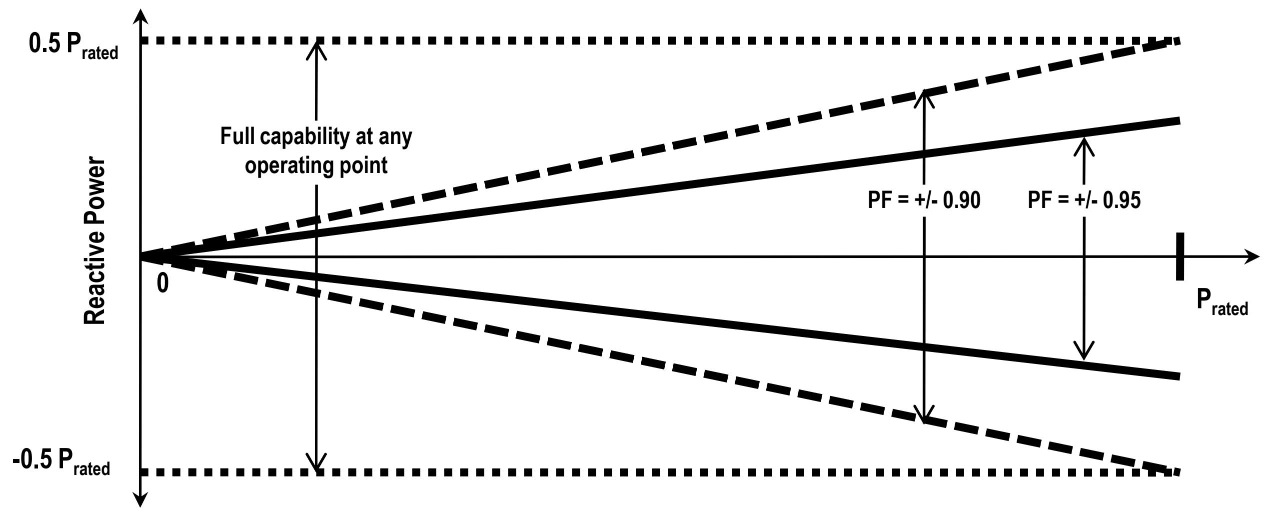
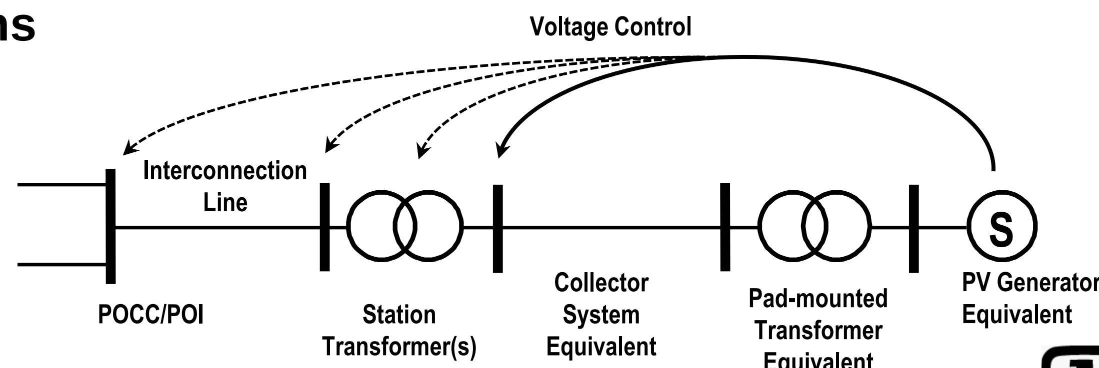
Power Flow Representation

Reactive Power Capability of Inverters: What is the reactive power capability? What about partial power? Check spec sheet!



Reactive Control Options

- Power factor
- Reactive power
- Voltage



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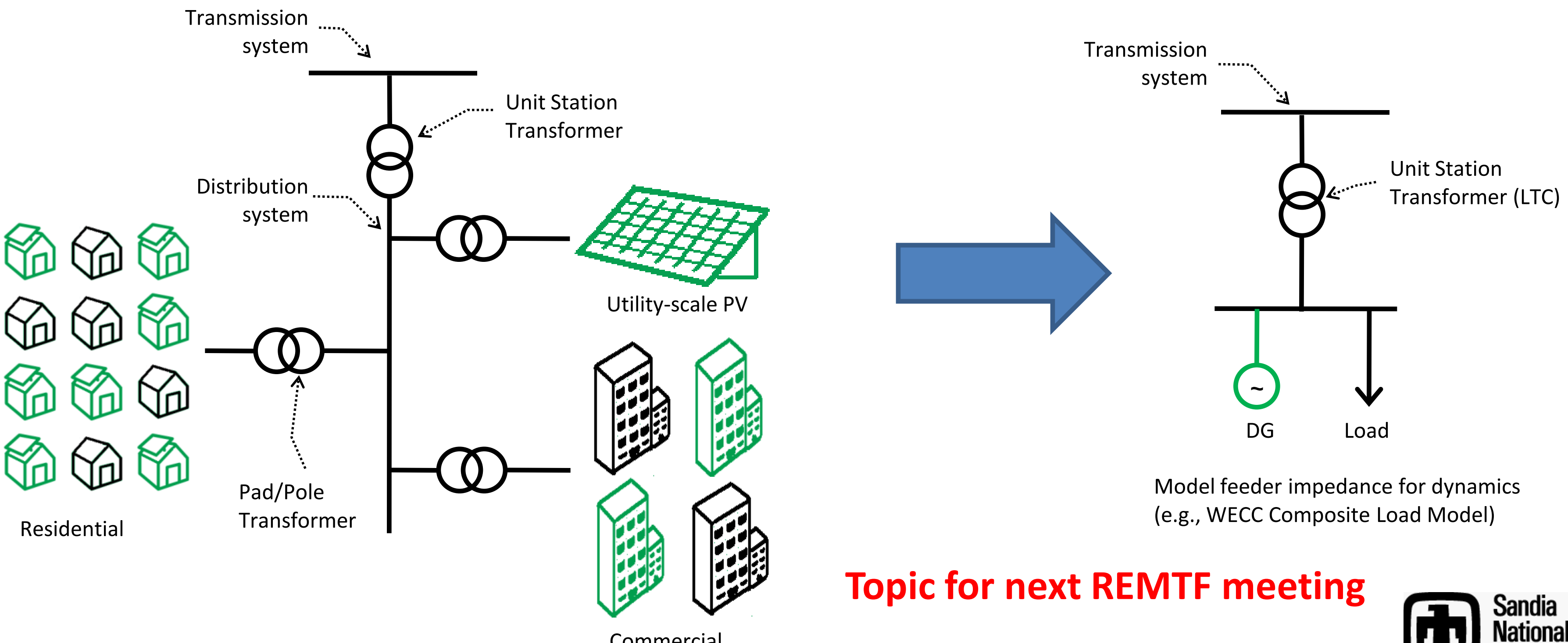
Power Flow Representation

- Modeling effect of high penetration distributed solar at the bulk system level
  - Key issue: tripping for transmission disturbances



Topic for next REMTF meeting

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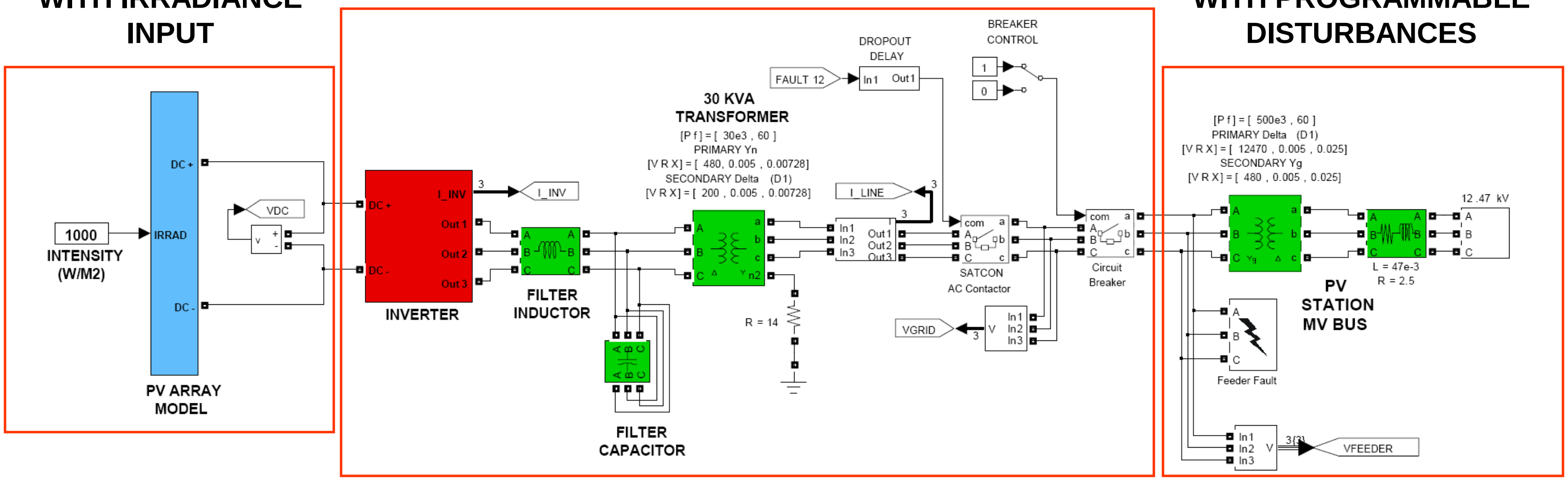
Transient Behavior

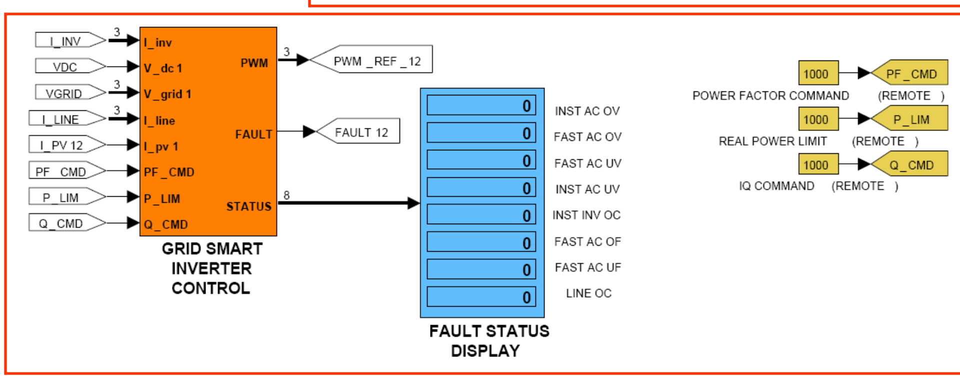
30 kW PV inverter example with advanced "Smart Grid" controls

PV ARRAY MODEL WITH IRRADIANCE INPUT

INVERTER + OUTPUT FILTER + TRANSFORMER

POWER SYSTEM WITH PROGRAMMABLE DISTURBANCES

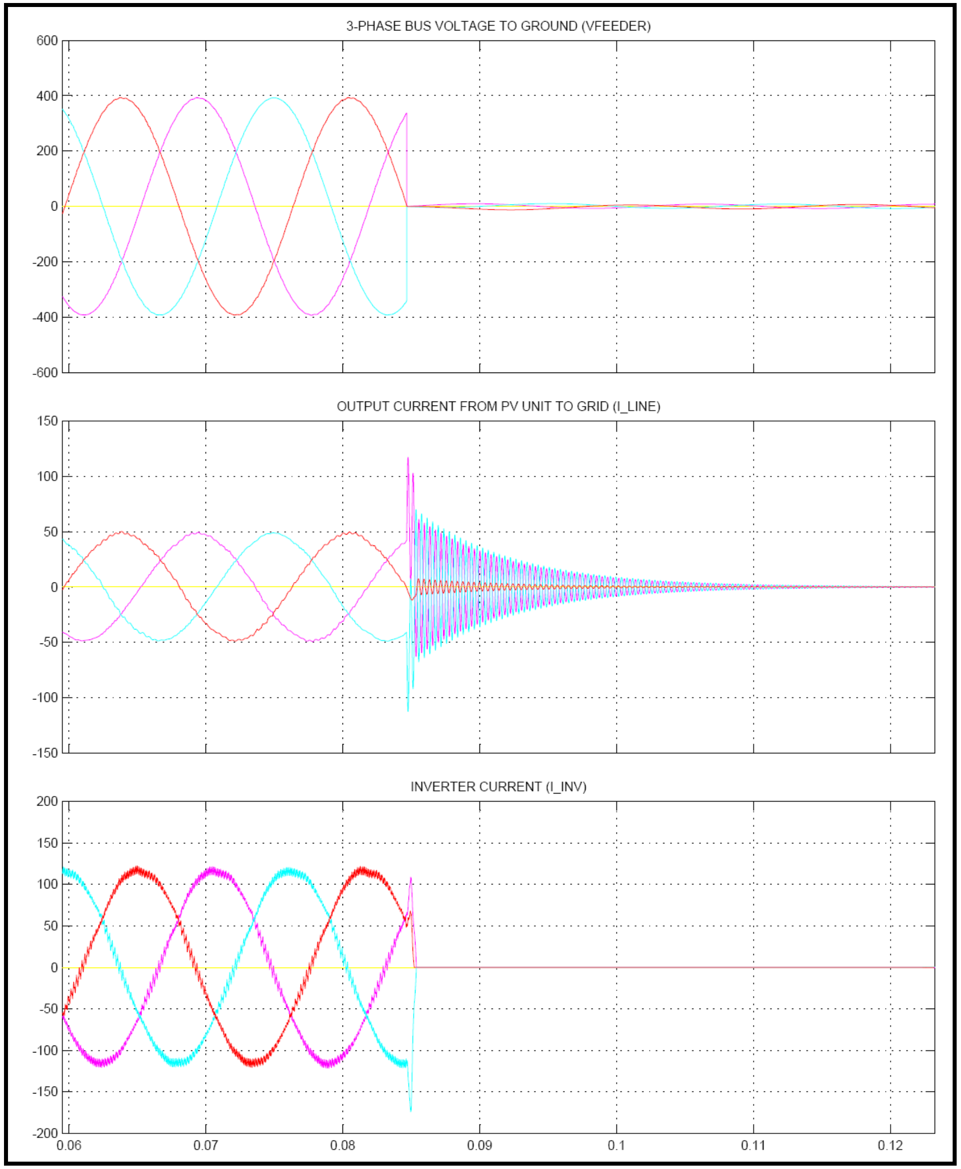




DETAILED CONTROL SYSTEM MODEL (MAY BE ENCRYPTED TO PROTECT PROPRIETARY DESIGN INFORMATION)

Source: Colin Schauder, Satcon Technology Corporation - Transient Modeling for Inverter-Based Distributed Generation, March 2, 2010

Transient Behavior



Grid Voltage Monitoring Enabled – Unit Trips During L-L-L-G Fault

In this case the AC voltage drops instantaneously and triggers an "instantaneous AC under-voltage" trip. Inverter gating stops immediately and the AC contactor releases after a few cycles. The filter capacitor rings with the grid inductance for a short time.

Source: Colin Schauder, Satcon Technology Corporation - Transient Modeling for Inverter-Based Distributed Generation, March 2, 2010

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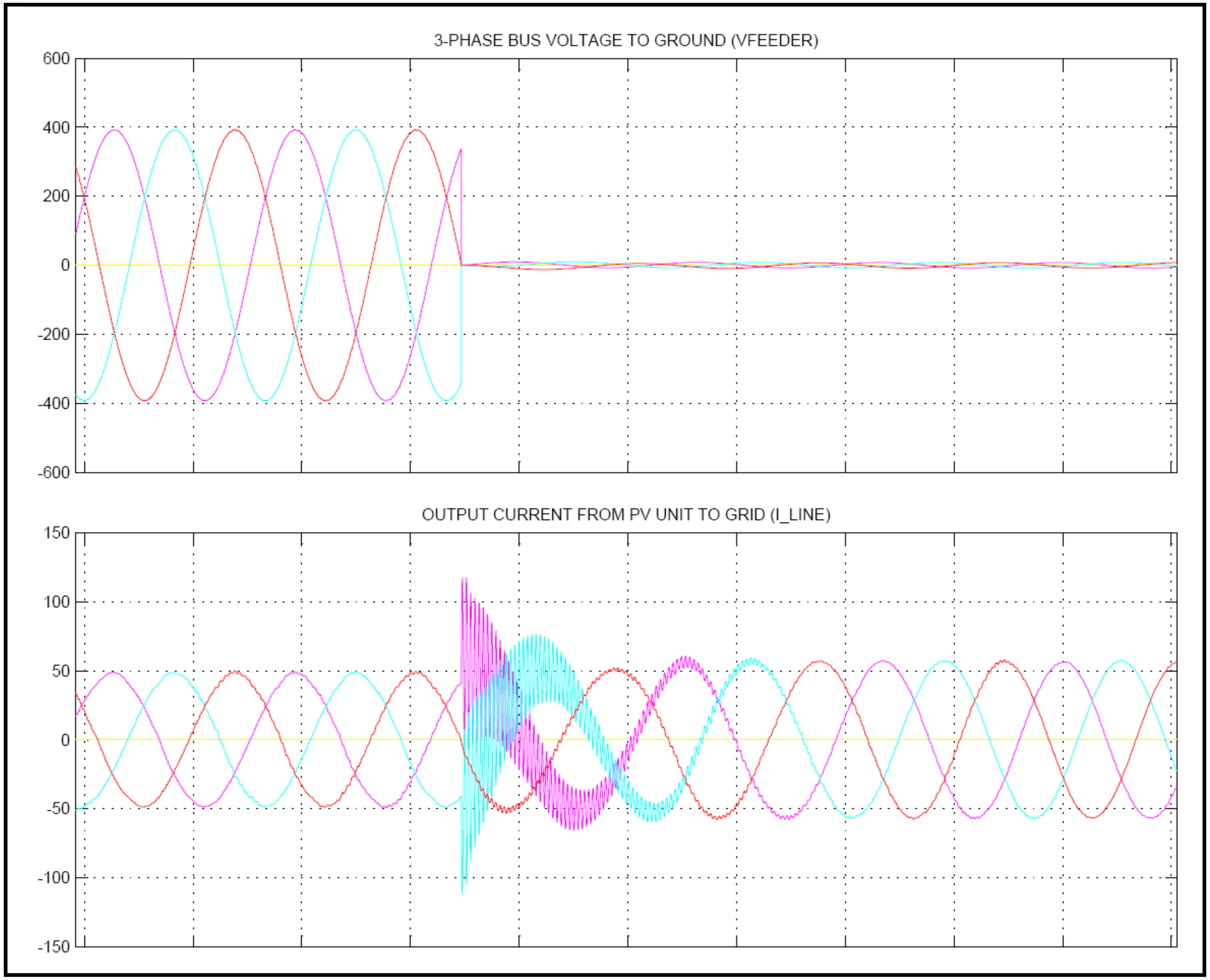
Transient Behavior



Grid Voltage Monitoring Disabled to Allow Ride-Through During L-L-L-G Fault

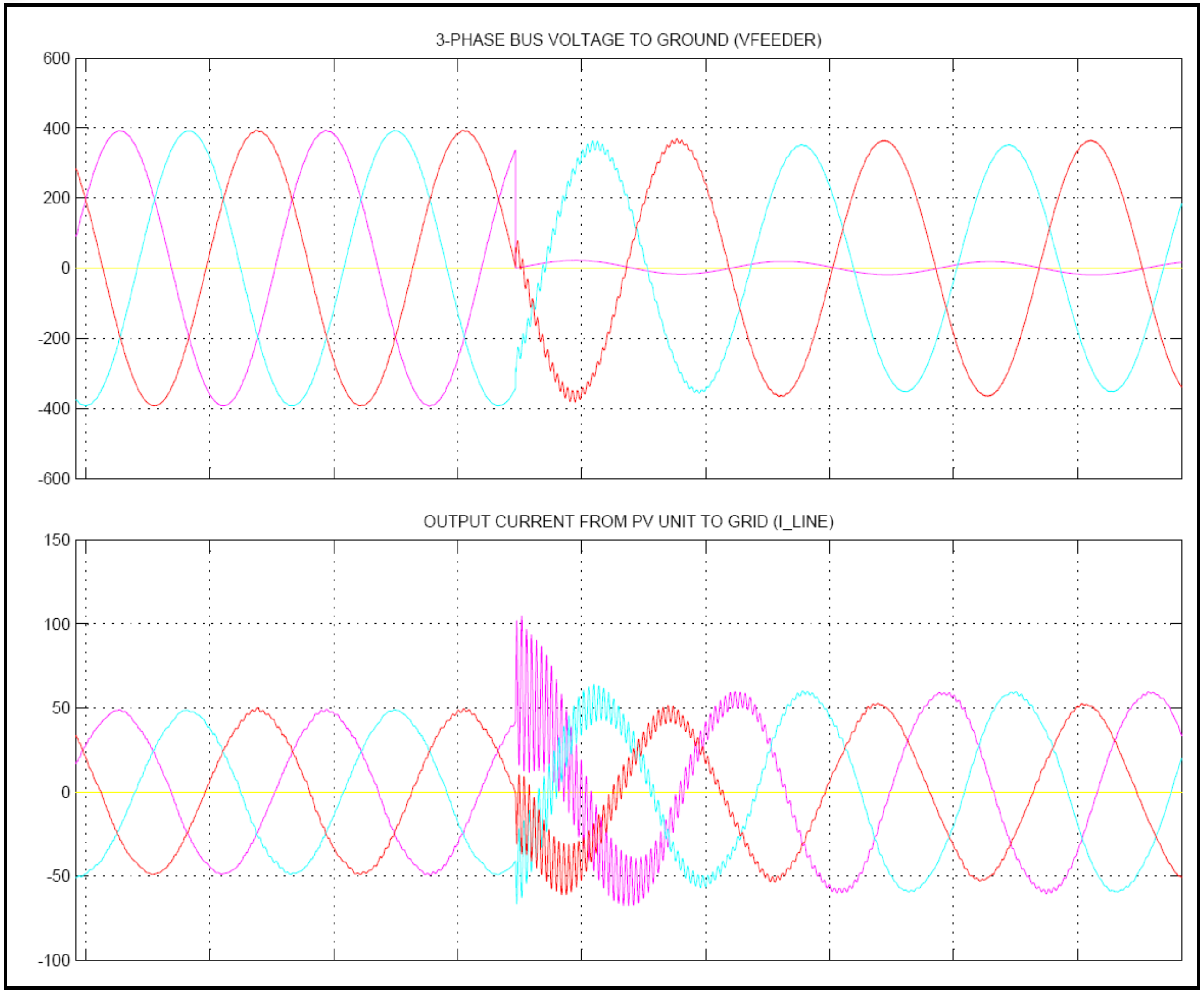
In this case the grid voltage monitoring has been disabled so the inverter keeps running (with limited 60 Hz current output).

Note the high frequency resonant discharge of the filter capacitor.

If the voltage drop is not so abrupt, then much less ringing occur.

Source: Colin Schauder, Satcon Technology Corporation - Transient Modeling for Inverter-Based Distributed Generation, March 2, 2010

Transient Behavior



Grid Voltage Monitoring Disabled to Allow Ride-Through During L-G Fault (D-Yg Feeder Transformer)

The grid voltage monitoring is disabled so the inverter keeps on running (with limited 60 Hz current output).

Again there is no transient over-voltage on the AC bus because the upstream transformer is connected D-Yg.

Compare with the case shown on the following slide, where the transformer is connected Y-Yg

Source: Colin Schauder, Satcon Technology Corporation - Transient Modeling for Inverter-Based Dis Generation, March 2, 2010

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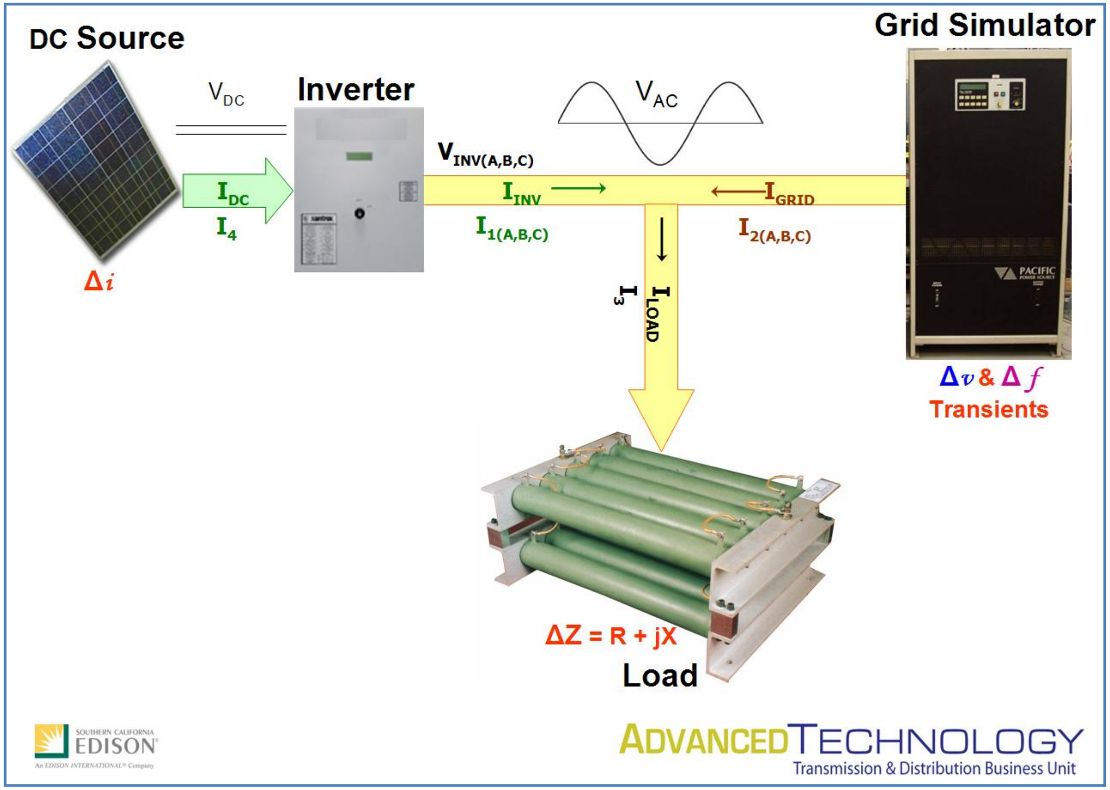
Model Validation/Verification

- Laboratory testing is first step
- Also need to validate against field data



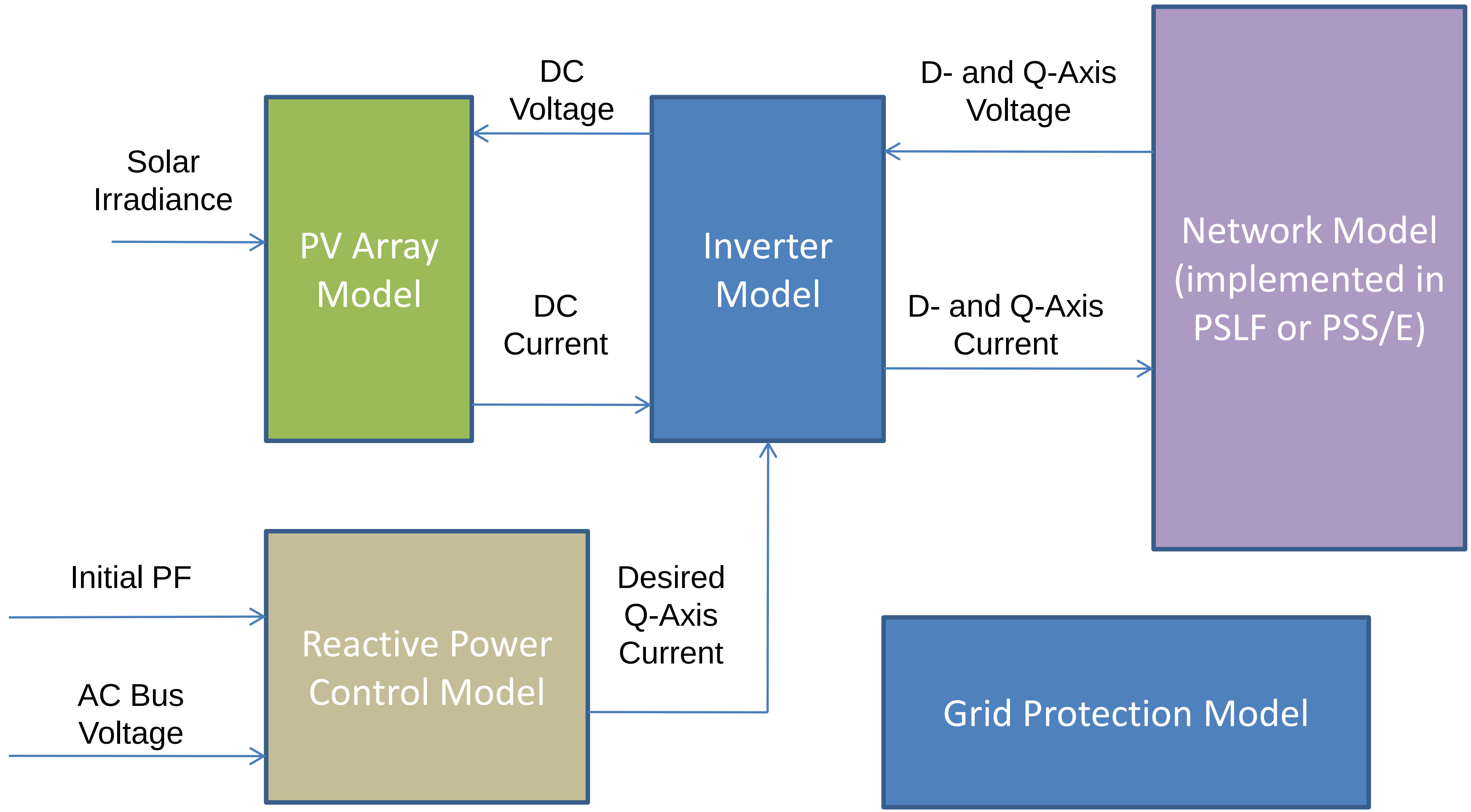
Source: Richard Bravo, SCE, 3-phase solar inverter test procedures (Draft)

REMTF working with SCE/NREL inverter characterization project

Dynamic Models – Basic Specs

- Approximate aggregate dynamic response for entire PV plant
- Suitable for simulation of grid events
  - 3-ph (up to 9 cycles) & 1-ph faults (up to 30 cycles) faults, frequency events, oscillatory events (up to 10 Hz bandwidth)
  - Assume constant irradiance during electrical disturbance
    - Model extension should handle irradiance input (user beware!)
  - Protection module to mimic “LVRT” curve (piecewise linear)
- Numerically stable with time steps of ¼ to ½ cycle
  - Faster internal integration may be needed for some important controls
- Include existing and emerging control options & capabilities
  - LVRT, Volt/Var control options, power control (ramp rate, transient limit, programmed inertia), frequency support
- Initializes from power flow without special scripts

Model Connectivity



Source: Mike Behnke, BEW Engineering – Proposal for Generic PV System Model, March 2, 2010

Summary

- Need to improve models of PV systems (both transmission-connected and distribution connected) to facilitate a range of grid studies
  - Interconnection, T&D planning and future scenarios
- Model features
  - Generic, non-proprietary, accessible
  - Include emerging control features and capabilities
- Some of the gaps being addressed
  - Specify/develop/validate/implement models, guidelines – a collaborative effort